Analytical Investigation of Soil Inorganic Nutrients of Cholistan desert - Pakistan

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Summary: Desert soil inorganic nutrients have their geological influence on wild medicinal herbs, plants and crop production. Soil samples collected from different areas of Cholistan desert were analysed for pH, moisture, soluble salts, organic contents, Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe^{3+}, Al^{3+}, Cl^-, CO_3^{2-}, HCO_3^-, SO_4^{2-} and PO_4^{3-}. pH was observed from 7.30 to 8.85. Average level of nutrients were found higher in the order Al^{3+} (432.66± 205.93) > Fe^{3+} (289.54± 160.77) > SO_4^{2-} (266.19± 215.59) > Cl^- (247.08± 284.48) > HCO_3^- (78.45± 161.44) > CO_3^{2-} (60.14± 41.26) > Ca^{2+} (53.16± 50.01) > Mg^{2+} (18.95± 19.39) > PO_4^{3-} (18.72± 24.20) > Na^+ (17.75± 15.34) K^+ (15.81± 18.51). Data analysis for soluble salts and CO_3^{2-} has showed negative skewness. Kurtosis data have shown random variations in results from positive to negative. Linear correlation coefficient matrix study has indicated strong positive correlation for certain pairs of nutrients.

Introduction

About 11 million hectors land of Pakistan comes under deserts like Cholistan, Thar, Kharan and Chagi. Ground water is mostly saline in these deserts. There is great need to utilize saline water and resources of desert economically, like UAE, for shifting them from unproductive to productive one through choosing well adapted plant species and producing food, timber, fuel and livestock [1, 2].

Around 4000 B.C. Cholistan was a cradle of civilization commonly known as the Hakra Valley civilization. Hot, arid and sandy Cholistan desert is an extension of Great Indian Desert with length of about 480 km and width of from 32 to 192 km. This desert is comprised of about 26 million hectares. The mean annual rainfall is about 100 mm to 200 mm. Mean minimum and maximum temperatures are 20 °C and 45 °C respectively. Dune land, sandy soil, loamy soil and saline sodic clayey soil form 44%, 37%, 2% and 17% of the whole desert soil respectively. The Cholistan was formed by deposition of aeolian sands or alluvium deposits from ancient Hakra and Sutluj rivers. The soil of Cholistan is generally saline, alkaline and gypsiferous [1-3].

Cholistan desert has a uniquely located wildland of its own kind with scarcity of endemic flora, counting only 115 species belonging to 28 families [4]. Some area (less desert) is under cultivation. There is no previous study to monitor the major inorganic nutrients of Cholistan desert soil. This study would be helpful in deciding the kinds of trees, crops and medicinal herbs cultivation in this soil environment.

Results and Discussion

Soil is a heterogeneous mixture of minerals, organic matter, water and air and soil fertility standard varies from plant to plant and crop to crop [5]. The study area soil (Table 1) has moisture contents 1.01-16.27 %, organic contents 2.46-8.80 %, and soluble salts 2.45-33.30 %. Moisture has correlations with Na^+, K^+ and SO_4^{2-}. Organic contents and Soluble salts have r = 0.412. The predominant part of the soil consists of sandy soils with clayey and loamy patches. In saline soils, high temperature causes salinity, induced drought and injury to plant. [6-11].

Uptake of various plant nutrients is pH dependent. Cholistan soil has pH 7.3-8.85, whereas in Northern areas of Pakistan soil pH is ≅ 4. More than 97% fields under investigation have shown soil pH 8.0 or above (Table-1) whereas the optimum pH required for normal crop cultivation should be 6.5-7.0 [5]. Strong positive correlation (Table-2) exists between soil pH and soluble salts (r = 0.581) and

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Table 1: Levels of inorganic nutrients of Cholistan desert soil.

Sample Code	pH mS/cm	Moisture %	Organic contents %	Soluble salts %	Na^+ (ppm)	K^+ (ppm)	Ca^{2+} (ppm)	Mg^{2+} (ppm)	Fe^{3+} (ppm)	Al^{3+} (ppm)	Cl^- (ppm)	CO_3^{2-} (ppm)	HCO_3^- (ppm)	SO_4^{2-} (ppm)	PO_4^{3-} (ppm)
1	7.72	16.25	3.24	2.45	10.56	2.34	96.15	33.62	287.75	220.75	55.96	70.30	12.31	436.43	0.45
2	7.71	3.42	3.57	4.47	20.23	3.79	32.35	28.85	288.95	440.31	78.45	77.80	8.95	326.92	0.25
3	7.66	16.27	2.46	6.78	20.34	5.85	80.18	51.37	430.46	515.62	71.95	74.60	10.86	254.84	0.36
4	8.27	1.01	4.20	20.50	6.03	4.87	1.14	0.56	286.63	215.25	0.49	75.62	13.40	149.76	12.61
5	8.85	2.04	8.80	21.95	7.07	8.01	0.98	0.48	289.51	435.15	0.49	105.17	17.70	110.88	25.22
6	8.22	2.00	3.90	20.50	5.96	5.14	0.84	0.96	285.49	431.60	0.77	83.18	14.90	166.08	47.53
7	8.45	1.20	2.80	23.00	11.12	4.15	0.96	0.30	282.45	389.28	0.59	123.16	16.25	266.88	51.41
8	7.78	7.14	4.48	15.38	10.05	35.00	6.00	1.28	860.37	735.18	17.82	90.10	410.13	100.75	0.13
9	7.60	3.45	7.40	10.29	10.20	10.15	0.27	0.21	229.89	145.78	78.48	60.30	106.61	200.53	0.29
10	7.30	13.63	3.93	14.50	10.00	10.00	0.14	1.26	172.97	882.61	71.27	110.12	600.10	250.62	0.25
11	7.80	12.10	8.30	15.10	40.00	40.00	78.35	50.26	268.75	730.22	635.12	0.29	1.19	864.51	6.19
12	8.20	9.70	9.50	19.60	35.05	10.45	48.27	9.60	335.64	215.63	426.31	8.48	4.58	28.91	2.58
13	7.40	6.50	7.20	17.40	5.89	16.36	40.17	19.22	201.85	390.73	497.15	10.07	7.07	50.09	2.56
14	8.30	10.40	7.80	21.70	60.00	15.87	56.36	19.73	67.93	140.21	213.83	2.63	10.87	251.36	16.71
15	8.20	11.80	6.70	18.20	20.09	70.63	60.85	21.64	300.12	460.34	659.97	6.96	7.98	242.77	45.83
16	8.10	6.80	4.10	5.10	40.45	44.78	144.05	62.31	100.87	310.29	710.16	5.87	6.91	763.61	85.34
17	8.21	1.05	4.50	21.20	8.95	0.96	135.18	26.37	210.62	520.64	340.26	57.36	17.62	190.93	11.96
18	8.21	2.07	8.50	33.30	3.38	7.67	116.94	20.96	280.56	630.55	810.13	80.34	12.73	220.72	5.89
19	8.78	1.50	3.00	22.69	11.85	4.28	110:89	10.98	320.42	410.36	25.36	100.22	210.39	180.94	40.12
Average	8.04	6.75	5.49	16.53	17.75	15.81	53.16	18.95	289.54	432.66	247.08	60.135	78.45	266.19	18.72
SD	± 0.43	± 5.36	± 2.35	± 7.81	± 15.34	± 18.51	± 50.01	± 19.39	± 160.77	± 205.93	± 284.48	± 41.26	± 161.44	± 215.59	± 24.20
Kurtosis	-0.45	-1.14	-1.51	0.03	1.93	3.30	-1.14	-0.04	9.27	-0.14	-0.87	-1.32	6.34	3.52	1.67
Skewness	0.12	0.53	0.38	-0.19	1.57	1.91	0.44	0.91	2.52	0.52	0.86	-0.34	2.60	1.90	1.46

phosphates (r = 0.534). The pH is peculiar property of soil that determines the acidity or alkalinity, which affects the chemical reaction between water and soil minerals. Alkaline soils with pH ranging 7-8 are generally deficient in Zn^{2+}, Fe^{3+} and P(V). Most of the primary nutrients like nitrogen, phosphorous and potassium and secondary nutrients like calcium, magnesium and sulphur are best utilized by the plants when the soil pH ranges 5.5-7.9. The uptake of most of the micronutrients also takes place at low pH [12]. Soil pH also influences the activity of micro-organisms. At pH 5.5, fungi and algae generally dominate the soil whereas at higher pH levels the bacteria are predominant [13].

The levels of sodium in soil of Cholistan desert are found to be 3.38-40.45 ppm. The higher sodium concentration (sample-16) in soil solution is known to cause detrimental effect on the growth of most plants [14]. In the present study, Na^+ pairs with K^+ (r = 0.379), SO_4^{2-} (r = 0.490) and Mg^{2+} (r = 0.499) for strong positive correlation. Physiologically sodium helps osmo-regulation, heat expansion and may act as a potassium substitute. However, high sodium concentration causes 'ionic toxicity' and imbalances in the Na^+/K^+, Na^+/Ca^{2+}, Na^+/Mg^{2+} ratio and may cause salt injury to crop [14].

Table 1 shows that potassium contents are ranged 0.96-70.63 ppm. The optimum levels required for crop cultivation are known to be 180-300 ppm and below 60 ppm deficiency symptoms may appear [20, 21]. In Cholistan desert soil, K^+ has strong positive correlation with Cl^- (r = 0.583), SO_4^{2-} (r = 0.406), PO_4^{3-} (r = 0.370) and Mg^{2+} (r = 0.335). Potassium is the major nutrient after nitrogen and phosphorous which is considered essential for plant growth. Potassium is an enzyme activator, increases photosynthesis and reduces the crop lodging [15, 16]. Potassium leaching and availability has become a limiting factor for crop production in many soils of Pakistan. The release and fixation of potassium is controlled by several factors such as properties of 2:1 soil type clay/mineral, structural configuration, and interlayer charge density [17]. The problem of potassium deficiency was of lesser extent in irrigated areas [17, 18].

Calcium levels in soil samples are ranged 0.14-144.05 ppm and show strong positive correlation with Mg^{2+} (r = 0.743), Cl^- (r = 0.596) and SO_4^{2-} (r = 0.450). Calcium deficiency symptoms generally occur below 500 ppm [19]. Increasing sodium salt may lead to precipitation of calcium with carbonates and bicarbonates [20]. Physiologically calcium is important in plant nutrition. It regulates the growth, IAA hormone, calmodulin barrier across the cell membrane to regulate the intercellular cation and anion balance [21].

The soil magnesium contents are ranged between 0.21-62.31 ppm with an average of 18.95 ± 19.39 ppm and has strong positive correlation with > SO_4^{2-} > Ca^{2+} > Cl^- > Na^+ > K^+. Magnesium deficiency generally occurs below 60 ppm [19]. Magnesium plays an active role in plant growth and metabolism. It regulates the ATP enzymes, carbon dioxide fixation, cellular pH control, chlorophyll content, chloroplast pigmentation, and many other functions of crop development [21]. Magnesium is present in dark coloured mineral soil and dolomitic limestone consists of calcium, magnesium and carbonates. In most soil complexes the amount of exchangeable magnesium is less than the exchangeable calcium [19].

The levels of iron are ranged from 67.93 - 860.37 ppm and have strong positive correlation (Table-2) with Al^{3+}, CO_3^{2-} and HCO_3^-. The young leaves of plants, growing in iron deficient soils, become yellow in the areas between the veins. The veins usually remain green, unless deficiency is severe, in which case the veins also turn yellow, and the whole leaf can eventually become white. It is the active iron (Fe^{2+}) component of total iron that is critical for iron nutrition of plants. In the presence of iron, a high contents of soil lime can saturate the soil solution with bicarbonate ions which are absorbed by the plants and due to which pH of leaf tissue rises and iron is rapidly converted from the active Fe^{2+} to inactive form Fe^{3+} and others [22-23].

The levels of aluminium are in the range from 140.21-882.61 ppm and have strong positive correlation with HCO_3^- (r = 0.590) and Fe^{3+} (r = 0.363). Aluminium is present as $[AlSiO_4]^-$ network in the soil, being hydrolysed by basic pH and remain insoluble as $Al(OH)_3$ [24-26].

Chloride levels in soil samples are ranged 0.49-810.13 ppm and show strong positive correlation with > Ca^{2+} (r = 0.596) > K^+ (r = 0.583) > Mg^{2+} (r = 0.540) > organic contents (r = 0.515) > SO_4^{2-} (r = 0.404) > Na^+ (r = 0.334). These are distributed in the form of salts of Ca, K and Na in soils. When absorbed by plant roots, chloride is transported to leaves, where it accumulates. This accumulation produces undesirable and damaging symptoms like leaf necrosis (often observed as marginal scorching) and leaf abscission. Woody species like camellias, rhododendrons, roses and stone fruits are particularly sensitive to chloride toxicity. Soil with chloride concentration in excess of 100 ppm can affect woody plants and sever problem occurs at levels over 300 ppm. Chloride can lower the availability of nitrate uptake due to competition of the roots for the uptake of ions [27, 28].

The levels of carbonates and bicarbonates are in the range from 0.29-123.16 ppm and 1.19-600.10 ppm respectively. Carbonates have strong positive correlation with HCO_3^- (r = 0.431) and Fe^{3+} (r = 0.332) whereas; bicarbonates have strong positive correlation with Al^{3+} (r = 0.590), Fe^{3+} (r = 0.343) and CO_3^{2-} (r = 0.431). Bicarbonates and carbonates have pH rising effect and precipitate some of the micronutrients rendering them unavailable to plants. Iron and aluminium deficiency is common because of this effect. Bicarbonates also have a physiological affect on the roots reducing nutrient adsorption and problem starts at around 75 ppm. If exceeds 150 ppm, the soil is probably not suitable. Bicarbonates and carbonates can be reduced by treatment with gypsum to precipitate them or with sulfuric acid to neutralize them [27, 28].

Sulphate levels in soil samples are ranged 28.91-864.51 ppm and show strong positive correlation with > Mg^{2+} (r = 0.749) > Na^+ (r = 0.490) > Ca^{2+} (r = 0.450) > K^+ (r = 0.406) > Cl^+ (r = 0.404) > soil moisture (r = 0.323) > PO_4^{3-} (r = 0.309). Plants are comparatively insensitive to sulphate toxicity.

Table 2: Linear correlation coefficient matrix for selected nutritive parameters studied in Cholistan desert soil. (n = 19).

	pH	Moisture	Organic contents	Soluble salts	Na^+	K^+	Ca^{2+}	Mg^{2+}	Fe^{3+}	Al^{3+}	Cl^-	CO_3^{2-}	HCO_3^-	SO_4^{2-}
Moisture	-0.538													
Organic contents	0.120	-0.006												
Soluble salts	0.581	-0.521	0.412											
Na^+	0.041	0.416	0.287	-0.195										
K^+	-0.075	0.332	0.245	-0.120	0.379									
Ca^{2+}	0.128	0.149	-0.050	-0.060	0.281	0.152								
Mg^{2+}	-0.233	0.470	-0.104	-0.504	0.499	0.335	0.743							
Fe^{3+}	-0.068	0.041	-0.175	-0.030	-0.319	0.111	-0.247	-0.221						
Al^{3+}	-0.281	0.157	-0.109	0.134	-0.251	0.193	-0.004	0.050	0.363					
Cl^-	-0.067	0.145	0.515	0.179	0.334	0.583	0.596	0.540	-0.289	0.136				
CO_3^{2-}	0.173	-0.367	-0.519	0.148	-0.692	-0.581	-0.377	-0.526	0.332	0.294	-0.697			
HCO_3^-	-0.340	0.169	-0.249	-0.037	-0.229	0.012	-0.305	-0.383	0.343	0.590	-0.323	0.431		
SO_4^{2-}	-0.158	0.323	-0.093	-0.438	0.490	0.406	0.450	0.749	-0.291	0.148	0.404	-0.349	-0.169	
PO_4^{3-}	0.534	-0.285	-0.232	0.083	0.172	0.370	0.220	0.152	-0.283	-0.184	0.185	-0.071	-0.222	0.309

Values>0.3 or < -0.3 are significant at $P < 0.01$

Table-3: Soil Sampling Locations.

Sample code	Sampling Areas.
1	Soil samples collected from Bahawalpur city i.e. Aziz abad colony (Urban).
2	Soil samples collected from Khanqah Sharif, Ganwar Shah road Bahawalpur.
3	Soil samples collected Faisal colony, Bahawalpur.
4	Soil samples collected from road side of the University Campus.
5	Soil samples collected from Bahawalpur city i.e. Riaz Colony.
6	Soil samples collected from Lodhran city.
7	Soil samples collected from Ahmad pur East (Urban).
8	Soil samples collected from Bahawalpur near Sutlej river.
9	Soil samples collected from the desert area of Bahawalpur Airport.
10	Soil samples collected near Chak No. 12 B. C.
11	Soil Samples collected from Engineering Department, Baghdad-ul-Jadeed campus Islamia University Bahawalpur.
12	Soil Samples collected from Green Belt, Baghdad-ul-Jadeed campus Islamia University Bahawalpur.
13	Soil Samples collected from Main roadside of Baghdad-ul-Jadeed campus Islamia University, Bahawalpur.
14	Soil samples collected near Cholistan institute of desert studies, Baghdad-ul-Jadeed Campus, Islamia University, Bahawalpur.
15	Soil samples collected near Electrical engineering department, Baghdad-ul-Jadeed Campus, Islamia University, Bahawalpur.
16	Soil samples collected from Model Town B, Bahawalpur.
17	Soil samples collected from Baghdad-ul-Jadeed Campus, Islamia University, Bahawalpur.
18	Soil samples collected from Bahawalpur (Rural).
19	Soil samples collected from Ahmad pur (Rural).

When the level of sulphate is about 3000 ppm, plant growth will be adversely affected [27, 28].

Phosphate levels in soil samples are ranged between 0.13-85.34 ppm and show strong positive correlation with > soil pH (r = 0.534) > K^+ (r = 0.370) > SO_4^{2-} (r = 0.309) [29-37].

Experimental

Materials

Nineteen soil samples, from surface to depth of 3 feet, were randomly collected from different areas of desert (Table 3) because main bioactivity lies up to these depths. Stones and gravel were removed from the soil samples, which were than air-dried, ground and sieved by 2 mm pore size sieve. The samples were preserved by using the method as described by Rowell [29]. The analysis were made for different cations and anions like Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe^{3+}, Al^{3+}, Cl^-, CO_3^{2-}, HCO_3^-, SO_4^{2-} and PO_4^{3-}

Chemical Reagents

All the reagents and chemicals used were of analytical reagent grade procured from Merck and Fluka. All the solution of standards and samples were prepared in deionised water using E.mil glasswares. Mettler PM 460 electric balance, Milwaukee pH meter and Corning- 40 flame photometer were used.

Soil Sample Preparation

25 g of dried soil was taken in a 500 ml beaker, stirred with 100 ml deionised water for 30 minutes and filtered through 'Whatman 42' filter paper. The volume of the filtrate was made up to one liter and was used for quantitative estimation of Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe^{3+}, Al^{3+}, Cl^-, CO_3^{2-}, HCO_3^-, SO_4^{2-} and PO_4^{3-}

Methods

Moisture percentage, soluble salts and soil pH

10 g soil sample was taken in a dried preweighed nickel crucible and heated in an oven at 110 °C until constant weight. Moisture contents were calculated by using the formula;

% Moisture in soil = weight of soil / weight of dry soil × 100

After soil sample preparation, dried the residue soil on filter paper at 110 °C until constant weight and soluble salt % were calculated using the formula;

% Soluble salt = Weight of dried soil before extraction / Weight of dried soil after extraction × 100

pH was determined by pH meter of supernatant water.

Total Organic Matter percentage

Heated the dried soil sample from above at 300 °C for 1 hour, cooled in desicator, weighed and repeated the procedure of heating and cooling till constant weight is achieved. Total Organic matter % was calculated using the formula;

% Total organic matter = Weight of dried soil / Weight of heated soil × 100

Determination of sodium and potassium

Sodium, and potassium were determined by using 'Corning-40 flame photometer. A calibration plot for sodium, and potassium with the help of Corning standards in the range of 10-70 ppm ± 0.1 % and 20-50 ppm ± 0.1 % were prepared respectively. From 'absorbance' verses 'concentration' plot, the concentrations of the unknown samples were calculated.

Determination of calcium and magnesium

Calcium and magnesium were determined by complexometric method, using EDTA as titrant. Ecriochorm Black T and Murexide as indicator. The measurement of calcium and magnesium were made with the standard deviation of ± 0.8 % [30-31].

Determination of iron and aluminium

Iron and aluminium levels in soil samples were estimated by precipitating with NH_4Cl/NH_4OH buffer solution and precipitates of $Fe(OH)_3$, $Al(OH)_3$ were complexed with oxine solution of 8-hydroxyquinoline. The precipitates obtained were filtered, dried and calculated the amount of iron and aluminium respectively [34, 35].

Determination of chloride, carbonates, bicarbonates, sulphate and Phosphates

Chlorides were determined by the standard argentometric method using potassium chromate indicator, carbonates and bicarbonates were determined by titrimetric method, sulphates were estimated using $BaSO_4$ precipitates and back titrating them with EDTA. Phosphates were determined by colorimetric method using 'ammonium dihydrogen phosphate' as standard solution and 'molybodate' as complexing agent [33, 37-41].

Statistical analysis

The data was statistically analysed by using SPSS 12 and STATSICA (StatSoft 1999) softwares on P-IV system. The concentrations of elements in soil and plant samples were correlated by linear correlation coefficient matrix (pearson).

Conclusions

High soil pH converts Ca^{2+}, Mg^{2+}, Fe^{3+} and Al^{3+} into their least soluble corresponding hydroxides. Excess sodium problem can be solved with the addition of calcium such as from gypsum, which, by dilution, lowers the relative activity of sodium. Calcium can precipitate bicarbonates and carbonates as well as supply sufficient calcium for plant needs. Sandy soils have rapid leaching of the salts and thus avoid large increase in soil salinity. Attention should be made by the authorities for the use of Cholistan desert soil for agricultural purposes.

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